S-PRINT: Development and Validation of a Tool to Predict, Evaluate, and Mitigate Excessive Workload Effects

Completed Technology Project (2012 - 2015)

Project Introduction

The purpose of this project was to research and model human performance in unexpected workload transitions. These situations, when addressed by fatigued astronauts, constitute worst case scenarios that require specific, in-depth investigation. The project addressed two NASA risk areas -- the risk of performance errors due to fatigue, and the risk of poor task design. In addition, the research provided input for the Human Automation/Robotic Interaction research area at NASA. The project conducted integrative reviews of what was known and unknown, addressed where there was insufficient or conflicting existing research or theory for adequate quantitative prediction, and combined these insights to produce a new mechanism to understand and predict performance. This last goal was accomplished through the development of a prototype model-based tool to be used by NASA human performance researchers, automation system designers, mission planners, and astronauts to evaluate predicted astronaut performance on long-duration space missions during unexpected workload transition scenarios. The tool enables users to identify the effects of astronaut fatigue, automation system design, and task factors on predicted astronaut performance in unexpected off-nominal events (e.g., automation failures or other emergencies). The tool developed in this effort, called the Space Performance Research Integration Tool (S-PRINT), leverages the Improved Performance Research Integration Tool (IMPRINT) human performance modeling environment, and tailors it to space mission applications. IMPRINT was developed for the Army Research Laboratory, and is available, free of charge, to U.S. government agencies. IMPRINT includes algorithms to study performance shaping factors such as fatigue, training, and use of protective clothing with human performance models. IMPRINT includes a sophisticated model of operator workload based on multiple resource theory. S-PRINT was developed based on extensive literature reviews and meta-analyses on fatigue, automation failure response, and workload overload. We systematically evaluated human-in-the-loop research to identify and quantify factors in long-term space missions that affect astronaut workload, fatigue, and performance. The results of these meta-analyses were used to update IMPRINT algorithms so they more accurately reflect space-specific conditions. In particular, the algorithms contain empirically validated models of sleep-related fatigue, automation failure management, and multitasking in workload overload situations. Further, the team conducted a series of focused human-in-the-loop studies to address specific components of performance that were not answered in the meta-analyses. The S-PRINT tool was developed so it can be used to evaluate performance in missions that are being planned or missions that are currently underway. The team identified two scenarios of interest for a prototype application of the tool. The primary scenario includes a single astronaut manually controlling a robotic arm when a failure occurs in the environmental process control system. When the astronaut notices the process control failure, s/he needs to prioritize among the different tasks. We worked with NASA subject matter experts (SMEs) to develop human performance models

S-PRINT: Development and Validation of a Tool to Predict, Evaluate, and Mitigate Excessive Workload Effects

Table of Contents

Tech Port

Printed on 12/15/2022
06:25 AM UTC

For more information and an accessible alternative, please visit:
https://techport.nasa.gov/view/23251

Page 1

that reflect those situations. The tasks combined in this specific type of situation were of sufficient complexity to be beyond the scope of previously existing models. The team conducted an empirical, human-in-the-loop validation study of the robotic and process control system tasks. A second scenario, involving fire detection and suppression systems, was also implemented and included with the S-PRINT tool. Our scenario development and research efforts focused specifically on worst-case situations: rapid workload transitions (e.g., automation failures, other off-nominal events) resulting in overload, with a single astronaut. The S-PRINT tool offers users access to the underlying IMPRINT modeling environment. Users who are familiar with human performance modeling can build their own, customized scenarios, and are not limited to the two scenarios developed for this project. S-PRINT also provides an easy-to-use interface in the form of data entry screens that guide the user through the process of building a scenario. It allows the researchers who are not modeling experts to specify numerous relevant factors, e.g., operators, tasks, automation support, use of protective clothing, and sleep history. The output of the model run (for both customized IMPRINT models and S-PRINT-specific models) includes parameters of interest such as operator workload, fatigue effects on task completion time and task accuracy, time to initiate tasks, time to complete tasks, results of task failures, and overall mission times, which can be used to compare relative success. The effort to provide a new, integrative framework proved highly successful. An empirical validation study of visual attention allocation predicted by the task overload model revealed high correlations (r > 0.95) with actual human performance. This research provided a validated model-based tool to help NASA researchers evaluate potential long-duration missions, identify vulnerabilities, and test potential mitigation strategies to help ensure effective performance and safe space missions. The tool and associated scientific advances offer important insights both for future space scenarios, and for a wide range of other real-world situations.

Anticipated Benefits

The S-PRINT project offers several potential benefits to human performance research and industry on Earth. These include contributions to the human performance literature and the development of a model-based tool to predict operator performance in workload transitions. The project resulted in numerous (19, as of March 2015) publications in peer-reviewed professional journals and conference proceedings. These publications describe different aspects of the human performance research conducted under the grant. In particular, two extensive meta-analyses were conducted to examine 1) the effects of sleep-related fatigue on complex task performance, and 2) the effects of task factors on task management, task switching and task shedding in overload situations. These analyses provided an empirically-derived basis for algorithms that were developed and implemented in the Improved Performance Research Integration Tool (IMPRINT) human performance modeling environment and, in particular, response to unexpected automation

Organizational Responsibility

Responsible Mission Directorate:

Space Operations Mission Directorate (SOMD)

Lead Center / Facility:

Ames Research Center (ARC)

Responsible Program:

Human Spaceflight Capabilities

Project Management

Program Director:

David K Baumann

Project Manager:

Brian F Gore

Principal Investigator:

Angelia Sebok

Co-Investigators:

Robert Sargent
Benjamin Clegg
Christopher D Wickens

TechPort

Printed on 12/15/2022
06:25 AM UTC

For more information and an accessible alternative, please visit:
https://techport.nasa.gov/view/23251

Page 2

failures. In addition to the meta-analyses, the project included multiple human-in-the-loop (HITL) studies to investigate 1) human-automation interaction (exploring, in particular, the effects of automation design factors and failure types on automation bias and complacency), 2) multitasking in overload situations. The results of these studies have been published and contribute to the scientific knowledge in human-automation interaction and human performance in overload. These two topic areas are relevant in numerous Earth-based domains. The second major contribution of the S-PRINT project was the development of component models to predict 1) the effects of fatigue (i.e., due to sleep deprivation, sleep restriction, sleep inertia, and circadian cycle effects) on task completion time and task accuracy, 2) the effects of automation design factors (e.g., reliability, degree of automation, or function allocation) on operator performance, 3) the effects of failure type on operator performance, and 4) the effects of task factors (i.e., salience, expectancy, effort, and value) on task selection in overload. These models have been implemented in IMPRINT. All of these areas are relevant in Earth-based industries that require around-the-clock operations, involve the use of automation, and offer the potential for situations that put an operator in overload conditions. Examples include medicine, process control, military operations, and transportation.

Primary U.S. Work Locations and Key Partners
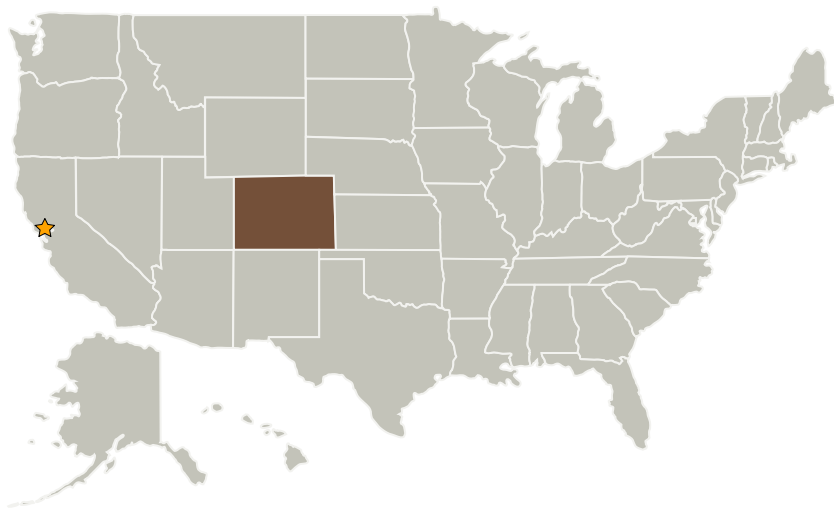
Technology Maturity (TRL)

Start: **4**
Current: **6**
Estimated End: **6**

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

Applied Research | Development | Demo & Test
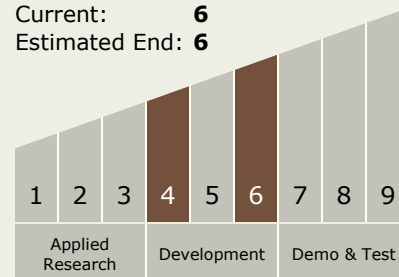
Technology Areas

Primary:

- TX11 Software, Modeling, Simulation, and Information Processing
  └ TX11.2 Modeling
    └ TX11.2.3 Human-System Performance Modeling

Target Destinations

The Moon, Mars

S-PRINT: Development and Validation of a Tool to Predict, Evaluate, and Mitigate Excessive Workload Effects

Completed Technology Project (2012 - 2015)

Organizations Performing Work	Role	Type	Location
⭐Ames Research Center(ARC)	Lead Organization	NASA Center	Moffett Field, California
Alion Science And Technology Corporation	Supporting Organization	Industry	Boulder, Colorado

Primary U.S. Work Locations
Colorado

Project Transitions

▶ **April 2012:** Project Start

TechPort

Printed on 12/15/2022
06:25 AM UTC

For more information and an accessible alternative, please visit:
https://techport.nasa.gov/view/23251

Page 4

March 2015: Closed out

Closeout Summary: The objective of this research was to develop tools and empirically-based guidelines that support human performance researchers, mission planners, automation designers, and astronauts in long-duration missions. Specifically, the products from this research will help users to (a) anticipate and avoid potential problems related to unexpected workload transitions by identifying the empirically established effects of operator fatigue, automation system design, and task factors on overload performance with particular emphasis on the fatigued operator's response to unexpected emergencies; and (b) assure that systems can be designed in such a way as to minimize transient or longer-term impacts on performance in space exploration missions. The proposed work contributes to the Program Requirements Document (PRD) by helping to mitigate both 1) risk of errors due to poor task design, and 2) risk of performance errors due to sleep loss, circadian cycle, fatigue, and work overload, especially in instances when high workloads are imposed by off-nominal events. Alion Science and Technology, together with Dr. Christopher Wickens, Colorado State University, and Dr. Thomas Jones, proposed to develop and empirically validate the S-PRINT tool. S-PRINT is based on human-performance models that are accessed through a usable interface. S-PRINT allows users to evaluate the effects of automation system design, operator fatigue, and task factors on predicted performance in automation failure scenarios. The project consists of three main lines of work: 1) literature review and meta-analyses, 2) S-PRINT model and tool development, and 3) empirical data collection and validation studies. The literature review and meta-analyses were conducted to identify and evaluate factors that affect astronaut performance on long-duration space missions. In our literature review effort, we identified three primary areas of research: 1) fatigue and underload effects on performance, 2) human-automation interaction, including factors such as automation reliability and operator complacency, and 3) overload, multitasking, and operator strategies for performing tasks in these conditions. These three areas were researched in parallel to provide a qualitative understanding of the issues (goal of the literature review), and to provide empirically-based data to inform human performance model development (goal of the meta-analyses). The review provided sufficient data to develop analytic models for predicting the effects of sleep disruption fatigue on complex task performance, and for developing a preliminary model of task selection in overload conditions. It also revealed a need for targeted empirical research in the areas of human-automation interaction and in task selection in overload. The S-PRINT model and tool development area included four main subtasks: 1) S-PRINT tool development, 2) human performance model development, 3) implementation of analytic models and performance shaping factors developed from the meta-analyses and targeted experimentation, and 4) beta test evaluation and tool improvements. These were all completed in the project. The S-PRINT tool was developed and the models were implemented and tested. S-PRINT is included within the Improved Performance Research Integration Tool (IMPRINT), a tool that Alion has developed and maintains for the Army Research Laboratory. IMPRINT allows users to build task network models to predict human performance in complex scenarios. S-PRINT allows users to develop and evaluate scenarios using a particular model of operator performance. S-PRINT, as delivered to NASA in March, 2015, includes two library models, and it also provides the capability for users at NASA to build their own custom models using IMPRINT. S-PRINT provides an easy-to-use interface that allows users to create, run, and compare scenarios using already-existing library models. By changing input parameters regarding astronaut fatigue, automation system design, and task characteristics, S-PRINT users can create literally thousands of scenarios. The output from these scenarios can be compared to identify sleep mitigations, automation design changes, allocation of individuals to tasks, or task factor changes that can be adjusted to provide better performance. In addition, S-PRINT was evaluated at a beta test performed with potential system users at NASA. We identified two scenarios for the basis of the library models. The primary deliverable in S-PRINT was a long-duration mission scenario that would impose significant mental workload on an astronaut. It is of an astronaut working with a remotely-manipulated robotic arm and monitoring an environmental process control system. A fault occurs in the process control system, and rapidly becomes a high-workload off-nominal event. We developed the model of this scenario using data from NASA trainers, astronauts, and from our robotics and process control simulations. Another model, involving an operator using one of three different types of fire detection systems, was developed for testing the S-PRINT human-automation interaction capabilities and for the beta test. The third task in the tool and model development area – implementing the analytic models and performance shaping factors – has also been completed. The fatigue meta-analysis provided algorithms that specify performance degradations based on sleep deprivation (hours of continual wakefulness), restricted sleep, circadian cycle effects, and sleep inertia. These algorithms, considerably expanding on existing algorithms (e.g., SAFTE) have been added to IMPRINT. The human-automation interaction (HAI) literature review provided a robust HAI framework and relative importance measures of different factors such as automation reliability and automation failure salience. However, to parameterize the HAI model further, we conducted targeted research. The data collected from the research allowed us to develop a performance shaping factor that applies a benefit to performance when the scenario includes 1) automation that is implemented at a high degree (where most of the functions are allocated to the automation rather than the operator) and 2) is highly reliable, if the automation is functioning normally. This performance shaping factor applies a pena

TechPort

Printed on 12/15/2022
06:25 AM UTC

For more information and an accessible alternative, please visit:
https://techport.nasa.gov/view/23251

Page 5

Stories

Articles in Other Journals or Periodicals
(https://techport.nasa.gov/file/56935)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56950)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56948)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56944)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56954)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56947)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56941)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56949)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56939)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56946)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56942)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56952)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56938)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56936)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56953)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56940)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56943)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56937)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56951)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/56945)

Project Website:

https://taskbook.nasaprs.com